

SEP-04-'91 13:14 ID:EW PROJ MGT

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AUG 28 1991

**Babcock & Wilcox**

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To	C. A. PALMBERG, PROJECT MANAGEMENT - BVCE3K	
From	E. F. RADKE (x6427), CE MECHANICAL ENGINEERING - BV802B	BOS 663-9
Cust.	INTERMOUNTAIN POWER PROJECT	File No. 5R or Ref. 334 - 0614
Subj.	FINITE ELEMENT ANALYSIS APPLIED TO BURNER DESIGN	Date AUGUST 26, 1991

This letter to cover one customer and one subject only.

This letter is to comment on and outline the effort that would be involved to use finite element analysis (FEA) to produce an improved burner design. In summary, it was concluded that FEA would be very difficult and expensive to use. The cost of a complex analysis may be a significant portion of the cost of the burners themselves and may still not provide realistic enough results.

The following paragraphs discuss some important aspects.

### FAILURE MECHANISM

from The primary concern is the binding of moving parts (e.g. registers) caused by plate distortion and attachment weld failures. Both the distortion and the weld failures result from high thermal differentials at very high temperatures. It is possible that some portions of the burner could have experienced temperatures over 1500F.

Plate distortion results from some or all of the following:

1. Elastic buckling followed by plasticity (yielding) to produce permanent deformation.
2. Elastic buckling followed by creep strain to produce permanent deformation.
3. Progressive magnification of as-manufactured imperfections (e.g., built-in waviness) by creep strain.
4. Inelastic (creep and/or yielding) strain due to thermal stress.

The differences between these mechanisms may appear subtle but their analysis requires some very different modeling approaches.

### THERMAL ANALYSIS

In order to solve for the thermal stresses in a structure, a definition of the temperature distribution over the whole structure is required. For this particular analysis, this fundamental requirement may be the most important and difficult to satisfy.

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Although not recommended, one approach would be all-analytical. There would be two modes of heat transfer to quantify:

Convection film coefficients would be very difficult to establish. A knowledge of the local air velocities throughout the model would be essential.

Radiation heat transfer would be even more difficult to characterize. For comparison, it has taken years and heavy effort to establish the properties of radiation on membraned wall geometries. In addition, radiation to a burner is more complex because it is a 3-D problem, while a membraned wall geometry is basically 2-D.

Without verification by measurement of temperatures, an analytical solution could contain a large error.

Another approach would be to measure many temperatures at various locations on burner sub-components. Then by interpolation, the temperatures for the remainder of the geometry could be calculated. Although the measurement of the temperature distribution could have its own set of problems, this approach is considered more reliable than an all-analytical approach.

### MATERIAL PROPERTIES

Material property data including expansion coefficient, modulus of elasticity, yield stress, time-independent stress-strain behavior, and creep strain vs. time and stress would be required for a stress analysis. At the very high temperatures involved, this data is rare or non-existent. (This is true for thermal properties as well if they would be required for a thermal analysis.)

Another aspect that can be difficult to cope with is the wide statistical scatter of some of the data when it is available.

### GEOMETRY

It is not yet possible to speculate how large the required finite element model might be. The burner is geometrically complex. For linear elastic structural FEA, this complexity is expensive. However, for elastic buckling and non-linear FEA, this complexity could completely stop an analysis. (In practical application, elastic buckling and non-linear FEA are limited to simple geometries.) How much of the geometry that would be necessary to be modeled, and what level of detail, would also depend upon a hypothesis that identifies the most important thermal differentials.

### ANALYSIS CONCEPTION

This section summarizes that procedure that might be used to do an analysis.

Because of the many uncertainties and assumptions required to complete a FEA it is not realistic to expect absolute failure prediction. Instead, the analysis would have to be comparative (existing vs. proposed). Each configuration would have to be run separately. Ideally, any errors due to a faulty assumption would be applied consistently to each model.

The following steps would be necessary to do a FEA:

1. Arrive at a hypothesis that identifies which thermal differentials are most important.

This narrows the scope so that the probability of success is higher. FEA can sometimes be used as a "fishing expedition" tool, however that is obviously inefficient and reduces the probability of success.

A qualitative understanding of the problem that would enable this hypothesis does not yet exist.

2. Measure temperatures as discussed above to determine the complete temperature distribution required for a thermal stress analysis.

It is conceivable that a faulty thermal distribution could invalidate a comparative analysis as well as an absolute analysis.

3. Determine the minimum required model size to find the elastically calculated thermal stresses.

4. Run a linear elastic FEA and then evaluate the solution validity by checking for stresses that are greater than yield. Also check for validity by estimating creep strain accumulation. (Assumes sufficient material property data is available.)

5. Run a linear elastic buckling analysis to check for thermal buckling. (Assumes the geometry can be simplified enough to make this analysis practical.)

6. Make a decision about whether or not non-linear analysis would be worthwhile.

All four mechanisms mentioned above on p.1 involve a non-linear aspect. Note that, if it is necessary to account for the non-linear aspects, the cost and the risk of unreliability jump up. One rule of thumb that has been used for cost estimating purposes is to use a factor of ten times the linear analysis cost to find the cost of a non-linear analysis. In addition, non-linear analysis models are limited to comparatively simple shapes; cylinders, plates, etc. These simple shapes may not be adequate to describe the problem.

### PROPOSED BURNER

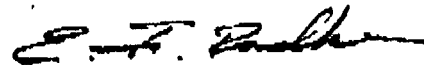
It is expected that this comparative analysis would show that the proposed configuration is better. There are three reasons:

1. The proposed burner design includes thicker plate to replace those that were damaged by distortion. Thicker plate will resist buckling better because the critical buckling stress is a function of  $t^2$  and  $t^3$  for flat plates and cylinders respectively (Roark, 5th ed., p. 550,556).
2. The proposed burner design utilizes slip-fit connections in order to minimize thermal growth restraint and eliminate the welds that had previously failed. Thermal stresses will not have a chance to build to the high levels experienced by the existing design.  
*initial*
3. A more heat resistant stainless alloy is used in the proposed design.

**CONCLUSION**

FEA is not a practical approach to producing an improved burner design. The obstacles are as follows:

1. A major effort would be required in order to define the thermal distribution.
2. Material property data may not be available.
3. The analysis may be too complex to handle reliably. Non-linear aspects of creep, plasticity, and large displacements could make the problem impossible to handle. Complex geometry compounds these difficulties.
4. The cost of an analysis may be high. It would be a significant fraction of the cost of a prototype burner itself.
5. Testing a full scale prototype would still be required to verify FEA results before committing to design changes.



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